USSN 09/882,338

#4

DESCRIPTION OF PREFERRED EMBODIMENT

The preferred embodiment embraces the system of my said copending application, now modified to incorporate the improvement of the current invention. These improvements, as before summarized, reside in the novel type and arrangement of accelerometer capacitances as additional input channels, as shown in Fig. 4; and the extension of the firmware processing performed in the microprocessor system to support the method of the invention, as flow-charted in Fig. 5. In addition, the static sensor channels have been increased in number and the associated sensors relocated to the corners with pairs of horizontally mounted coil springs now employed.

Fig. 1 depicts the force and torque sensing platform 5 in use as a computer touch input device for locating and otherwise measuring touches delivered to the display device 2, shown as a CRT display montior 11. The touch force generated by the user's hand 1 at point P passes through CRT display monitor 2, then in parallel through a tilt-swivel base 3 and stabilizer bar and bracket 4 provided with platform device 5 to a top plate 7 and the

condition:

$$f_u = A \ddot{f}_u + B a . \qquad (2$$

"C" is defined to be the six by twelve matrix formed by appending the rows of "B" after the corresponding rows of "A". There may be "n" measurement vectors in a calibration set collected as described.

Assume that a six by "n" matrix of uncorrected force readings "R_u" is formed by taking the first six components (derived from 71, Fig. 5) of each measurement vector, in order, as a column of "R_u". Let twelve by "n" matrix of correction channel readings "R_{cc}" be formed by taking the the last twelve components (derived from 72 and 73, Fig. 5) of each measurement vector, in order, as a column of "R_{cc}". Then we have:

$$R_u = C R_{cc} . \qquad (3$$

In general, no "C" will exactly solve equation 3 -- it is inconsistently overdetermined, due to redundant but slightly noisy data. Yet many will very nearly do so, since "C" is at the same time underdetermined, in that some modes of disturbance are

represented poorly or not-at-all in the calibration data. Thus we must look for a best fit "C", but not usually the one that gives the absolute minimum residual on the determining data. Rather, we wish to find that matrix to use for "C" which minimizes the expected value of the sum of the squares of the components of the error matrix "E" for:

$$E = R_{u2} - C\,R_{cc2}\,, \qquad (\ 4$$

where "R_{u2}" and "R_{cc2}" constitute a second set of independently determined calibration data on exactly the same installation, but with "C" determined from the original calibration data "R_u" and "R_{cc}".

We begin from the singular value decomposition of "R_{cc}":

$$R_{cc} = U\,W\,V^{T}\,, \qquad (\ 5$$

where column orthogonal matrices "U" and "V", and diagonal matrix "W have the usual definitions, and the calibration program calculates these using standard methods. The calibration program then obtains "C" from:

$$C = V\,W_{z}^{-1}\,U^{T}\,R_{u}\,. \qquad (\ 6$$

"W^{-1}" may be obtained from "W" by replacing each diagonal

element "w_{ii}" with its scalar reciprocal "$1/w_{ii}$". "W_z^{-1}" is obtained in a similar manner, except that zero is substituted for "$1/w_{ii}$" for each singular value "w_{ii}" which is too small. By "too small" is meant a determination assigned heuristically by the program to any singular value which is smaller than a certain percentage (such as one percent) of the greatest singular value, or which has an absolute value too close to the noise floor. This noise floor may be observed in the singular values obtained from data gathered as though performing a calibration, but with measurement groups artificially triggered in the absence of any disturbance. The best heuristics are a function of the application and the exact embodiment, and are determined empirically by repeated trials of differing relative and absolute thresholds; that pair of values is then chosen which actually minimizes expression 4 for multiple independently collected data matrices.

While a serviceable value of "C" may often be obtained by using "W^{-1}" for "W_z^{-1}" in expression 6, use of the latter provides not only better average correction,

USSN 09/882338

#4

1

--1. A method of measuring force and/or torque to be applied to a mechanically movable or disturbable system, including, where desired , objects associated therewith and portions of force measuring apparatus itself, that comprises, sensing one or more components of force and/or torque applied to the system by deliberate forces acting thereupon to provide force and/or torque measurements uncorrected by inertial interference motion effects that arise; deriving time derivatives including at least a set of the second order derivatives of the uncorrected force measurements and subtracting the same in different combinations of each order in turn from each channel of uncorrected force measurement, with coefficients of combination chosen such that the resulting sums reflect the desired force measurements substantially free of inertial motion interference errors.--

--2. A method of measuring force and/or torque to be applied to a mechanically movable or disturbable system, including, where desired, objects associated therewith and portions of force measuring apparatus itself, that comprises, sensing one or more components of force and/or torque applied to the system by deliberate forces acting thereupon to provide force and/or torque measurements uncorrected by inertial interference motion effects that arise; intentionally moving and disturbing the system in various ways while the said deliberate forces ultimately to be measured are not applied and are allowed to remain at zero, in order to generate measurements that enable calibration of the system that renders the same less prone to force measurement errors due to motions of the type created by said moving and disturbing.--

--3. Apparatus for measuring force and/or torque to be applied to a mechanically movable or disturbable system, including, where desired, objects associated therewith and portions of force measuring apparatus itself, having, in combination, means for sensing one or more

components of force and/or torque applied to the system by forces acting thereupon to provide force and/or torque measurements uncorrected for inertial interference motion effects that arise; means for sensing lineal and/or rotational acceleration of the system in response to such inertial interference motions; and means for correcting the uncorrected force and/or torque measurements in response to the acceleration sensing to achieve elimination from the measurements of the effects of such inertial interference. –

–4. Apparatus as claimed in claim 3 and in which said uncorrected force measurements are made and said acceleration is sensed for all relevant degrees of freedom of motion in a plurality of respective channels, and means is provided for adding different linear combinations of the acceleration-sensing channels in turn to each channel of force measurement, with coefficients of combinations chosen such that the resulting sums reflect the desired force measurements substantially free of inertial motion interference errors. –

–5. Apparatus as claimed in claim 4 and in which means is provided to derive time derivatives including at least a set of the second order derivatives of the uncorrected force measurements and to enter the same in different linear combinations of each order in turn in each channel of force measurement further to correct the same. –

–6. Apparatus as claimed in claim 5 and in which calibration means is provided including means for intentionally moving and disturbing the system in various ways while the force ultimately to be measured is allowed to remain at zero, with means for generating a correction matrix the elements of which comprise the desired coefficients of combination to achieve the corrections of the force measurements in each channel. –

–7. Apparatus as claimed in claim 6 and in which means is provided for deriving the coefficients of combination for the correcting channels at the display. –

–8. Apparatus as claimed in claim 3 and in which the mechanically movable or disturbable system is a weighing system. –